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COMBATANT SEAKEEPING SENSITIVITY STUDY

by
Darren Sheinberg
Timothy C. Smith

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This study examines the sensitivity of seakeeping predictions for three different ship classes. The sensitivity parameters were displacement, KG and trim The three ships hulls were the CG-47, and DDG-51 Flights I and IIA. The results consist of the percent difference from the median condition for every combination of parameters.

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ABSTRACT

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INTRODUCTION

Often seakeeping predictions are made for a ship class using a representative loading conditions as the actual loading condition changes over a voyage and over the ship's lifetime. This study addresses the issue of seakeeping prediction sensitivity to the boundaries of operational loading conditions. The parameters varied are displacement, KG, and trim. The range of the parameters varied with respect to ship class and parameters.

Three combatant ship hulls, CG-47, DDG-51, and DDG-51 IIA, were investigated. The ship class loading parameters came from a year 2000 listing of ship full load conditions. Cruise variation are examined to the extent the variation is within the range of full load parameters for a given class. The Spruance Destroyer class (DD-963) is actually the same hull form as the CG-47 and not evaluated separately. The median to maximum operational displacements of the DD963 overlap the minimum and median displacements of the CG-47. As such basic trends for the CG-47 can also be applied to the DD-963.

The seakeeping program used for the evaluation was the Navy Standard Ship Motion Program, SMP95[*,†]. SMP95 is similar to previous versions in terms of calculations, but different in software organization. Output consist of tables of irregular seas motion responses. The responses are tabulated by degree of freedom, significant wave height, heading, speed, and modal period. The SMP95 heading convention is: 0 deg is head seas and 180 deg is following seas.

METHOD

Baseline versions of three combatant ship hulls, CG-47, DDG-51, and DDG-51 IIA were identified. The maximum, minimum, and median operational values of displacement, KG, and trim were identified. They resulted in 27 possible combinations. They compose the corners, faces, and edges of a cube representing the parameter space. The median displacement, KG, and

[*] Meyers, W.G., T.R. Applebee, and A.E. Baitis, " User's Manual for the Standard Ship Motion Program, SMP," DTNSRDC Report SPD-0936-01 (Sep 81)

[†] Meyers, W.G. , and A.E. Baitis, "SMP84: Improvements to Capability and Prediction Accuracy of the Standard Ship Motion Program SMP81," DTNSRDC Report SPD-0936-04 (Sep 85)

trim condition is the center of the cube and designated the baseline. However, the median trim was changed to zero trim so make it easier to compare the results to previous data.

These different condition input files were created as follows. First, the change in draft was calculated to match the desired displacement based on the median hull waterplane area, using the following equation in English units.

$$\frac{(\rho g Awp(\delta T)}{2240} = \delta\Delta$$

Where ρ is the density of the salt water; g is the acceleration due to gravity; δT is the change in draft; $\delta\Delta$ is the change in displacement; and Awp is the waterplane area. The ship was trimmed about the LCF instead of midship or LCB after matching displacement. Trim was positive bow up.

SMP95 was run for each of the loading conditions with the same sea condition. The sea condition was defined by a significant wave height of 10.7 ft and modal periods of 5,7,9,11, and 13 seconds. This represents a range of mid Sea State 5 environments, which provides a level of response that could be easily compared.

On completion, the seakeeping results were taken from each output file and compared to the baseline case. The files were compared using the difference as the percentage of the largest value for each response. This was done because if the percent difference were calculated with respect to each data point, the data would appear to magnify insignificant differences. For example, comparing 0.1 to 0.3 has a 200% difference, but if both are compared to 5, their difference is smaller, 4%. Defining the difference as the percentage of the largest value produces reasonable differences.

The average difference and standard deviation of the difference for a given response over the entire condition cube were calculated. Also tables of the largest difference for each response were generated. The percent differences can be positive and negative. A positive difference occurs when the results are greater than the baseline results; the percent difference is negative when the results are less than the baseline results. Bold text in the tables indicates the largest positive differences; italicized text in the tables indicates the largest negative differences.

CG-47

The matrix conditions were examined for the CG-47 hull form. Table 1 shows the maximum, median, and minimum values used to determine the conditions. The average percent difference over the speeds, headings, and modal periods considered were mostly less than 0.34% for all response. The largest average percent difference for heave, roll, and pitch were 0.72, 1.33, and 0.89%, respectively. The standard deviation of the percent differences for all conditions were mostly less than 1%, though largest values were greater than 1% for all response, except surge and heave. Roll had the largest standard deviation of percent difference, 4.02%. Tables 2-7 give largest difference for a given displacement-KG-trim combination for each response. The largest difference gives a better measure of the maximum variation.

Table 1. Parameter values for CG-47.

	Displ. (long tons[‡])	KG (ft[§])	Trim (ft)
Maximum	10145	23.53	1.39
Minimum	9666	23.04	-0.02
Median	9897	23.34	0.825

The greatest surge difference, 8.27%, was at 20 knots, 135 degrees and modal period of 5 seconds. The average of the maximum percent differences was 2.78±4.38%. Table 2 shows the greatest surge percentage difference by condition. Generally an increase in surge was associated with minimum displacement. Though, the combination of maximum displacement and maximum trim resulted in the largest increase in response. Combinations of maximum or median KG with median or minimum trim produced surge reduction regardless of displacement in almost all cases.

Table 2. Greatest surge percentage difference for CG-47 by condition.

KG / Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	**8.27**	*-4.49*	*-4.43*	**7.60**	*-1.12*	*-1.06*	**7.51**	5.25	5.17
med Disp	5.85	*-4.69*	*-4.67*	3.21		0.14	5.90	5.03	5.03
min Disp	6.34	*-4.44*	6.36	3.85	0.79	3.76	5.92	5.21	5.92

The greatest sway difference, -10.41%, was at 30 knots, 120 degrees and modal period of 11 seconds. The average of the maximum percent difference is 4.94±2.53%. Table 3 shows the greatest surge percentage difference by condition. There was no real trend with respect to displacement. The largest sway decrease occurred for combinations of minimum KG-maximum trim. The maximum KG percent differences tended positive and to be the same regardless of displacement or trim. The median and minimum trim values tended to be similar for a given displacement and KG.

Table 3. Greatest sway percentage difference for CG-47 by condition..

KG / Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	-4.46	**5.13**	**5.16**	-8.72	1.67	1.67	*-10.41*	-7.05	-7.06
med Disp	**4.86**	**5.30**	**5.33**	-1.30		0.27	*-7.39*	-5.97	-5.97
min Disp	**5.10**	**5.58**	**5.13**	-2.07	-0.92	-2.08	*-7.02*	-5.73	-7.00

The greatest heave difference, 3.42%, was at 30 knots, 0degrees and modal period of 13 seconds. The average of the maximum differences was 1.19±1.44%. Table 4 shows the greatest

[‡] 1 long ton = 2240 lbs = 1.016 tonne
[§] 1 ft = 0.3048 m

heave percentage difference by condition. The combination of maximum displacement and maximum trim resulted in the largest increase in heave response. The maximum trim conditions had increased heave response for other displacements as well. There was no trend with respect to KG.

Table 4. Greatest heave percentage difference for CG-47 by condition.

KG	max	max	max	med	med	med	min	min	min
Trim	max	med	min	max	med	min	max	med	min
max Disp	**3.33**	0.81	0.84	**3.25**	0.72	0.73	**3.42**	0.79	0.82
med Disp	2.62	-0.47	-0.45	2.59		0.06	2.68	-0.23	0.21
min Disp	2.13	-1.26	2.14	2.07	-1.00	2.10	2.14	-1.15	2.13

The greatest roll difference, -22.86%, was at 30 knots, 120 degrees and modal period of 9 seconds. The average of the maximum percent differences was 4.04±15.59%. Table 5 shows the greatest roll percentage difference by condition. There was no strong trend with respect to displacement. The maximum trim conditions had the largest positive difference for a given displacement-KG combination. The maximum percent difference did increase with increasing KG. The combination of minimum KG and median or minimum trim resulted in the greatest decrease in roll.

Table 5. Greatest roll percentage difference for CG-47 by condition.

KG	max	max	max	med	med	med	min	min	min
Trim	max	med	min	max	med	min	max	med	min
max Disp	**19.81**	12.87	13.01	**8.00**	4.05	4.07	**20.59**	*-22.58*	*-22.44*
med Disp	**17.01**	12.24	12.35	**5.75**		0.88	-19.09	*-22.86*	*-22.73*
min Disp	**18.60**	13.75	18.74	**6.53**	1.66	6.68	**19.76**	*-21.32*	19.75

The greatest pitch difference, -4.55%, was at 30 knots, 60 degrees and modal period of 9 seconds. The average of the maximum percent differences is –0.88±2.63%. Table 6 shows the greatest pitch percentage difference by condition. There was no trend with respect to KG. The combination of maximum/minimum trim and median/minimum displacement resulted in decreases in pitch. Avoiding maximum trim condition at maximum displacement avoids the largest increases in pitch motion.

Table 6. Greatest pitch percentage difference for CG-47 by condition.

KG	max	max	max	med	med	med	min	min	min
Trim	max	med	min	max	med	min	max	med	min
max Disp	**3.80**	0.89	0.89	**3.71**	0.80	0.75	**3.75**	0.80	0.80
med Disp	*-3.24*	0.28	0.33	*-3.24*		-0.05	*-3.28*	-0.28	-0.28
min Disp	*-4.03*	-1.27	*-4.55*	*-4.03*	-1.13	*-4.50*	*-4.08*	-1.13	*-4.50*

The greatest yaw difference, -11.33%, was at 15 knots, 45 degrees and modal period of 5 seconds. The average of the maximum percent differences was –1.31±6.66%. Table 7 shows

the greatest yaw percentage difference by condition. The most apparent trend was with respect to KG. Yaw tended to decrease with increasing KG. The maximum trim conditions tended to have more yaw reduction than median or minimum trim conditions. The largest increase was at the minimum KG/minimum displacement condition.

Table 7. Greatest yaw percentage difference for CG-47 by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	*-11.33*	-6.02	-6.06	*-10.63*	2.75	2.66	*-10.22*	6.62	6.62
med Disp	*-6.86*	-6.16	-6.16	*-2.99*		-0.37	7.04	6.62	6.62
min Disp	*-7.74*	-6.53	-7.79	*-4.01*	1.77	-4.10	**7.60**	**7.04**	**7.60**

As ship displacement and KG tend to increase over the life of the ship, avoiding the maximum trim condition may not result in a motion reduction, but will mitigate the large increases seen in heave, roll, and pitch.

DDG-51 FLIGHT I

The matrix of conditions were examined for the DDG-51 Flight I hull form, hull numbers 51 to 71. Table 8 shows the maximum, median, and minimum parameter values used to determine the conditions. Deviation from the median position resulted in very little change either positive or negative. The average difference over all speeds, headings, and modal periods was less than 0.10% for all responses. The maximum average percent differences are 0.28, 0.43, and 0.25 % for heave, roll, and pitch, indicating an increase in response. The standard deviation of the percent differences were small, less than 0.40%, except for roll which was 1.25%. This indicates little change in response due the parameter change.

Table 8. Parameter values for DDG-51 Flight I.

	Displ. (long tons)	KG (ft)	Trim (ft)
Maximum	9045	24.32	0.62
Minimum	8803	23.85	-0.02
Median	8926	24.04	0.32

The greatest surge difference, 6.25%, was at 150 knots, 150 degrees and modal period of 5 seconds, as seen in Table 9. The average of largest differences was 2.69±2.75%. There was no consistent trend for any of the parameters. The combination of maximum or median displacement and minimum KG had the largest percent increase for all trims. Also the conditions with maximum trim always had an increase in response.

Table 9. Greatest surge percentage difference for DDG-51 Flight I by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	2.57	*-2.75*	*-2.74*	1.34	0.54	0.61	**6.22**	**6.11**	**6.12**
med Disp	3.75	3.19	5.71	0.72		-0.11	**6.25**	**6.19**	**6.19**
min Disp	4.87	4.45	4.42	1.09	0.70	0.67	1.33	1.19	1.19

The greatest sway difference, 9.65%, was at 15 knots, 135 degrees and modal period of 5 seconds, as shown in Table 10. The average of maximum differences was 1.39±4.82%. Like surge, the combination of maximum or median displacement with minimum KG had the largest percent increases for all trims. The median and minimum trim conditions were generally similar; the maximum trim conditions generally resulted in a response reduction.

Table 10. Greatest sway percentage difference for DDG-51 Flight I by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	*-2.58*	1.15	1.15	*-1.37*	0.88	0.80	**9.11**	**9.65**	**9.63**
med Disp	*-2.78*	-1.52	-4.85	*-1.72*		0.10	**9.18**	**9.52**	**9.52**
min Disp	*-4.08*	2.15	2.15	*-3.20*	-1.09	-1.25	*-2.19*	-1.13	-1.15

The greatest heave difference, 1.17%, was at 25 knots, 15 degrees and modal period of 11 seconds, see Table 11. The average of the maximum percent differences was 0.36±0.53%. There was no trend with respect to KG. The maximum trim conditions all had an increase in response; the median and minimum trim conditions were similar to each other. For a maximum displacement, the median and minimum trim conditions had negative maximums. The minimum displacement conditions had opposite trend of the maximum displacement conditions, i.e., the median and minimum trim conditions had positive maximums.

Table 11. Greatest heave percentage difference for DDG-51 Flight I by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	0.94	*-0.22*	*-0.21*	0.94	*-0.21*	*-0.21*	0.94	*-0.22*	*-0.22*
med Disp	0.96	-0.07	**1.17**	0.94		-0.03	0.94	-0.22	-0.24
min Disp	**1.01**	0.24	0.24	**1.00**	0.24	0.24	**0.98**	0.26	0.24

The greatest roll difference, 12.57%, was at 15 knots, 135 degrees and modal period of 9 seconds, as seen in Table 12. The average of the largest percent differences was 1.73±7.27%. The percentage difference decreased with increasing displacement. The trend with respect to KG was strong, percent difference increasing with increasing KG. There was no trend with respect to trim.

Table 12. Greatest roll percentage difference for DDG-51 Flight I by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	**10.22**	8.87	9.00	0.86	-1.58	-1.47	*-6.66*	*-7.80*	*-7.70*
med Disp	**10.58**	**10.41**	8.75	0.66		-0.04	*-6.25*	*-6.37*	*-6.40*
min Disp	**12.57**	**12.43**	**12.52**	2.22	1.99	2.07	-4.61	-4.74	-4.67

The greatest pitch difference, 1.34%, was at 0 knots, 105 degrees and modal period of 5 seconds, as shown in Table 13. The average maximum difference was 0.02±0.66%. The trends were opposite for the maximum and minimum displacement conditions. For the combination of maximum displacement and maximum trim pitch increased over the baseline. With minimum

displacement and maximum trim, pitch decreased. The median and minimum trim conditions were almost the same for a given displacement and KG. There was no trend with respect to KG.

Table 13. Greatest pitch percentage difference for DDG-51 Flight I by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	**1.20**	-0.29	-0.29	**1.20**	-0.29	-0.29	**1.20**	-0.24	-0.24
med Disp	*-0.86*	-0.10	1.34	*-0.86*		0.05	*-0.82*	0.24	0.24
min Disp	*-0.77*	0.24	0.24	*-0.77*	0.29	0.29	*-0.77*	0.29	0.29

The greatest yaw difference, -4.94%, was at 25 knots, 120 degrees and modal period of 5 seconds, see Table 14. The average maximum difference was –1.12±2.55%. For yaw, there was no definitive trends with respect to displacement or trim. Generally, the maximum displacement conditions had less yaw. The median and minimum trim conditions had similar values to each other. The maximum KG conditions had reduced yaw regardless of displacement or trim.

Table 14. Greatest yaw percentage difference for DDG-51 Flight I by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	*-3.23*	*-2.91*	*-2.91*	0.92	-0.97	-0.97	*-3.37*	*-3.60*	*-3.60*
med Disp	*-2.86*	*-3.05*	*-4.94*	-0.97		0.05	**3.46**	**3.33**	**3.28**
min Disp	*-3.23*	*-3.33*	*-3.33*	-2.40	1.16	-1.20	2.03	1.76	1.76

There was little difference in heave and pitch over the range of parameters. Operate at the minimum KG to reduce roll condition regardless of displacement. The minimum KG conditions tended to have increase in surge and sway.

DDG-51 FLIGHT II A

The matrix conditions were examined for the DDG-51 Flight IIA hull form, hull numbers 72 and above. Table 15 shows the maximum, median, and minimum values used to determine the conditions. Overall, the average differences as a percentage of largest value were less than 0.1 percent for all motions, except heave, which was 0.18%. The standard deviation for all motions was 0.43%. The average of the maximum percentage changes for all responses was 2.78%. Heave and pitch had the smallest average maximum percentage change, 0.84 and 1.03%, respectively. Typically the shorter periods had larger percent differences.

Table 15. Parameter values for DDG-51 Flight IIA.

	Displ. (long tons)	KG (ft)	Trim (ft)
Maximum	8962	24.28	0.78
Minimum	8738	24.02	0.22
Median	8913	24.14	0.62

The greatest surge difference,13.27%, was at 10 knots, 180 degrees and modal period of 5 seconds, as seen in Table 16. The average of largest differences was –2.40±5.07%. The largest differences were seen with the maximum KG condition, with an absolute average value of -7.7%. The minimum KG condition had absolute differences around 2%. The median KG with median trim condition had the least difference. There were no real trends with respect to displacement and trim.

Table 16. Greatest surge percentage difference for DDG-51 Flight IIA by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	*-6.48*	*-7.26*	*-6.93*	-7.11	-0.50	0.91	3.41	-2.92	-2.77
med Disp	*-6.69*	*-7.13*	*-7.29*	0.71		-0.31	2.38	-2.60	-2.48
min Disp	**13.27**	*-6.69*	*-7.26*	-7.48	1.26	-7.84	1.78	1.97	1.68

Sway had similar trends as surge. The greatest sway difference, -7.27%, was at 20 knots, 150 degrees and modal period of 5 seconds, as shown in Table 17. The average of the largest difference was –0.59±3.68%. The largest differences were seen with the maximum KG condition, with an absolute average value of 5.07%. The minimum KG condition had differences around 2%. The median KG with median trim condition had the least difference. There were no real trends with respect to displacement and trim.

Table 17. Greatest sway percentage difference for DDG-51 Flight IIA by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	*-7.27*	**4.85**	-4.71	**4.83**	0.23	-0.56	-2.21	-2.07	-2.01
med Disp	*-5.64*	**4.64**	4.52	-0.72		-0.24	-2.07	-2.01	-1.93
min Disp	*-5.67*	-4.15	4.20	**4.75**	-0.93	4.81	-2.10	-2.06	-1.96

The greatest heave difference, 2.30%, was at 25 knots, 0 degrees and modal period of 11 seconds, see Table 18. The average of the largest differences was 0.83±0.71%. The maximum trim conditions had the greatest differences. The differences also increased with increasing displacement. The median and minimum trim and displacement conditions were all similar in value. There was no trend with respect to KG.

Table 18. Greatest heave percentage difference for DDG-51 Flight IIA by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	**2.29**	0.22	1.00	**2.30**	-0.10	0.98	**2.27**	-0.10	0.98
med Disp	1.27	0.22	0.37	1.25		0.37	1.25	0.03	0.35
min Disp	1.42	0.38	0.47	1.27	0.38	0.47	1.27	0.38	0.47

The greatest roll difference, 8.37%, was at 20 knots, 120 degrees and modal period of 7 seconds, as shown in Table 19. The average maximum difference was 2.37±4.32%. The

maximum and minimum KG conditions had the greatest differences, 8.37 and –5.76%, respectively. The largest differences for the maximum and median displacement conditions were similar. The minimum displacement conditions had positive largest differences, indicating an increase in roll. The greatest reduction in roll was at the minimum KG conditions. There was no trend with respect to trim.

Table 19. Greatest roll percentage difference for DDG-51 Flight IIA by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	**6.28**	**4.97**	**5.49**	2.92	-0.90	1.27	5.05	*-5.76*	*-5.34*
med Disp	**6.44**	**5.86**	**6.08**	1.51		0.40	*-4.52*	*-4.88*	*-4.69*
min Disp	**8.02**	**8.37**	**6.93**	3.33	2.61	2.90	3.78	2.57	2.87

Pitch is independent of KG, like heave. The greatest pitch difference, -2.52%, was at 30 knots, 75 degrees and modal period of 7 seconds, as seen in Table 20. The average of the largest differences was –0.95±0.84%. The maximum trim conditions had the greatest differences, -1.88% average. The average of the minimum trim conditions was -0.78%. The maximum displacement conditions had above average pitch reductions. There was no trend with respect to KG.

Table 20. Greatest pitch percentage difference for DDG-51 Flight IIA by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	*-2.52*	0.34	-1.16	*-2.52*	0.15	-1.11	*-2.52*	0.15	-1.11
med Disp	*-1.50*	0.34	-0.44	*-1.45*		-0.44	*-1.45*	-0.15	-0.44
min Disp	*-1.79*	-0.53	-0.77	*-1.60*	-0.53	-0.77	*-1.60*	-0.53	-0.77

The greatest yaw difference, -4.60%, was at 15 knots, 135 degrees and modal period of 5 seconds, as shown in Table 21. The average of the largest differences was –1.05±3.05%. The maximum KG conditions had the greatest absolute differences, 4.18% average. The average absolute difference for the minimum KG cases was 1.72%. The median KG condition with the median and maximum displacements had the lowest difference. The maximum trim cases were slightly larger than the median and minimum cases. There was no trend with respect to displacement.

Table 21. Greatest yaw percentage difference for DDG-51 Flight IIA by condition.

KG Trim	max max	max med	max min	med max	med med	med min	min max	min med	min min
max Disp	*-4.43*	**4.18**	*-4.18*	-4.60	-0.84	0.67	2.09	-2.18	-1.34
med Disp	*-4.27*	**3.97**	*-4.06*	1.55		0.42	1.30	-1.51	-1.30
min Disp	*-4.18*	*-4.10*	*-4.27*	-4.43	**3.01**	-4.52	2.84	1.30	1.67

The minimum KG condition with maximum draft resulted in the largest roll reduction. Maximum trim tends to decrease pitch, sway, and yaw, but increase heave. Changing displacement did not significantly change trends established by KG and trim.

CONCLUSIONS

SMP was used to investigate the sensitivity of seakeeping predictions on three ship combatant ship classes. The parameters varied were displacement, KG, and trim. The difference was expressed as the percentage of the largest value for a given response.

Overall, the average difference percentage was less than 1% for all the responses and all the ship classes. The standard deviation of the differences was also small, but tended to reflect the magnitude of the largest differences. The largest differences averaged 0.24%±0.30% for all responses and ship classes. The greatest differences occurred around the upper speeds of 25 and 30 knots. Each class of ship experienced high roll differences.

Generally, the maximum trim conditions resulted in larger motions. Roll was reduced by the maximum displacement /minimum KG condition – often difficult to obtain in practice.

The practice of evaluating a representative hull for class is acceptable, especially if only vertical motions are of interest. The change in roll, while having large maximum percent differences, is modest elsewhere. The maximum difference in the order of 1-1.5 deg. Using a specified or known KG value if available is preferred to using a representative value.

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